19

Ionizing Radiation Profile of the Hydrocarbon Belt of Nigeria

Yehuwdah E. Chad-Umoren
Department of Physics, University of Port Harcourt, Choba, Port Harcourt, Nigeria

1. Introduction

Man and his environment are constantly bombarded with naturally occurring ionizing radiation. However, aside from the radiation occurring naturally in the human environment, there are those resulting from man's activities. These anthropogenic activities result in the elevation of the background ionizing radiation levels mainly through the depletion of the ozone layer so that an increase occurs in the amount of cosmic radiation reaching the earth (Foland et al, 1995). One crucial area of human activity is the hydrocarbon industry. Globally, the hydrocarbon industry is a strategic industry, contributing to the wealth of nations and the prosperity of individuals. Global economy is often appreciably impacted by the stability or otherwise of the industry. Furthermore, much of the world's population is dependent on the industry for its energy needs. Significantly also, the processes and techniques of oil and gas exploration, exploitation and usage contribute to the devastation, pollution and degradation of the environment.

In Nigeria, the hydrocarbon industry is reputed to be the highest user of radioactive substances in the country (Chad-Umoren and Obinoma, 2007). And the Niger Delta region of Nigeria plays host to the largest concentration of companies in this sector. The maze of crisis-crossing pipelines in the region (Fig.1) does not only transport oil and gas, but also dangerous radioactive substances so that the environment is not despoiled only during oil spillage, but is also polluted with harmful ionizing radiation. Also abundant in the region are numerous non-oil and gas industries and operations that have been attracted into the region by its oil and gas wealth.

2. History and status of the hydrocarbon industry in Nigeria

Oil was discovered in the Niger Delta of Nigeria in 1956 at Oloibiri in present day Bayelsa state and Shell D'Arcy Petroleum commenced production there in 1958. However, before this period, the German company, the Nigerian Bitumen company, had unsuccessfully drilled fourteen (14) wells in the area between 1908 and 1914 within the eastern Dahomey Basin (NNPC, 2004). By the year 2004, oil production had risen to 2.5 million barrels per day. It is estimated that Nigeria's recoverable crude oil reserves stand at about 34 billion barrels, while the nation's natural gas reserves stand at 163 trillion cubic feet (Tcf) making Nigeria one of the top ten nations with natural gas endowments. The current development plan projects that by year 2020, production will increase to 4million barrels per day.

Though government policy had envisaged that gas flaring will end by 2010, about 50% of the natural gas is still wastefully flared (ECN, 2003), while 12% is re-injected to enhance oil recovery. An estimate by Shell shows that about half of the 2 Bcf/d of associated gas and gaseous by-products of oil exploitation is flared in Nigeria annually, while the World Bank's estimates put Nigeria's gas flaring at 12.5% of the world's total gas flared.

Fig. 1. A map showing network of pipes of a major oil company in the Niger Delta

3. Industrialization and ionizing radiation in the Niger Delta

A number of ionizing radiation surveys have previously been carried out in the Niger delta region to assess the impact of industrialization on the radiation profile of the region and a strong correlation has been established between high industrial activities and elevated background ionizing radiation (BIR) levels for parts of the region (Avwiri and Ebeniro, 1998; Chad-Umoren and Briggs-Kamara, 2010). Ebong and Alagoa (1992 a, b) studied the background ionizing radiation profile at the fertilizer plant at Onne, Rivers State. The study reported a significant increase in the background radiation indicating that the presence of the fertilizer plant had a negative impact on the radiation levels of the area. A survey of the external environmental radiation in the Trans-Amadi industrial area and at other sub-industrial areas of Port Harcourt showed an average value of 0.014 mRh^{-1} (Avwiri and

Ebeniro, 1998). Comparing this result to the standard background radiation level of $0.013mRh^{-1}$, the study showed that there was a significant elevation in the radiation status of the surveyed areas which can be attributed to the industrial activities there.

Chad-Umoren and Obinoma (2007) surveyed the background ionizing radiation patterns at the campus of the College of Education at Rumuolumeni in Rivers State. The work gave a low radiation dose equivalence of 0.745±0.085mSv/yr as the average for the campus. It was also suggested that further studies needed to be done to assess the impact of the presence of a nearby cement production plant on the radiation status of the college. Briggs-Kamara et al (2009) studied the ionizing radiation patterns of the Rivers State University of Science and Technology at Port Harcourt. The major focus of the study was to assess the impact of computer and photocopier operations on the environmental ionizing radiation patterns of the campus. Computers and photocopiers are widely used on Nigerian university campuses without any consideration for their health hazards. The study established that in deed these devices contributed to the radiation levels of the campus.

A study was also carried out to determine the radiation levels in solid mineral producing areas of Abia state (Avwiri et al, 2010). Solid minerals have their origin in the earth's crust where the primordial radionuclides such as ^{238}U, ^{232}Th and their progenies are found. Consequently, mining of solid minerals has the potential to impact the environmental ionizing radiation. The radiation exposure rate for the surveyed areas ranged between 14.7 μR/hr to 18.2 μR/hr indicating an elevation over the normal background radiation level of 11.4 μR/hr for the host communities. Considering this elevated radiation level, it was concluded that the mining activity had future radiological health hazards for the miners, the general populace and the environment.

The Niger delta region constitutes the hydrocarbon belt of Nigeria and our aim in this work is to study the impact of oil and gas and its ancillary services on the ionizing radiation profile of the region (Fig. 2). Furthermore, based on international practises, we have also suggested appropriate strategies for the control of the ionizing radiation from the hydrocarbon industry and therefore make the activities of the industry in Nigeria more environmentally friendly. And in conclusion we have suggested possible areas for further work.

4. Geology, physiography and evolution of the Niger Delta

The Niger-Delta forms one of the world's major hydrocarbon provinces. It is situated on the Gulf of Guinea on the west coast of Africa and in the southern part of Nigeria, lying between longitudes 4 – 9°E and latitudes 4 - 9° N (Fig. 1) with an estimated area exceeding over 200,000 square kilometres (Odigie, 2001). It is composed of an overall regressive clastic sequence, which reaches a maximum thickness of about 12km (Evamy et al, 1978) and is divided into three formations: Benin formation, Agbada formation and Akata formation. The Agbada formation consists of sand, sandstone and siltstones and is the principal host of Niger Delta petroleum (Beka and Oti, 1995). The Akata formation forms the base of the transgressive lithologic unit of the delta complex and is of marine origin. It is composed of thick shale sequence (potential source rock), turbidite sand (potential reservoir in deep water) and minor amounts of clay and silt (Avbovbov, 1998). The tectonic framework of the continental margin along the west coast of Equatorial Africa is controlled by Cretaceous fractured zones expressed as trenches and ridges in the deep Atlantic.

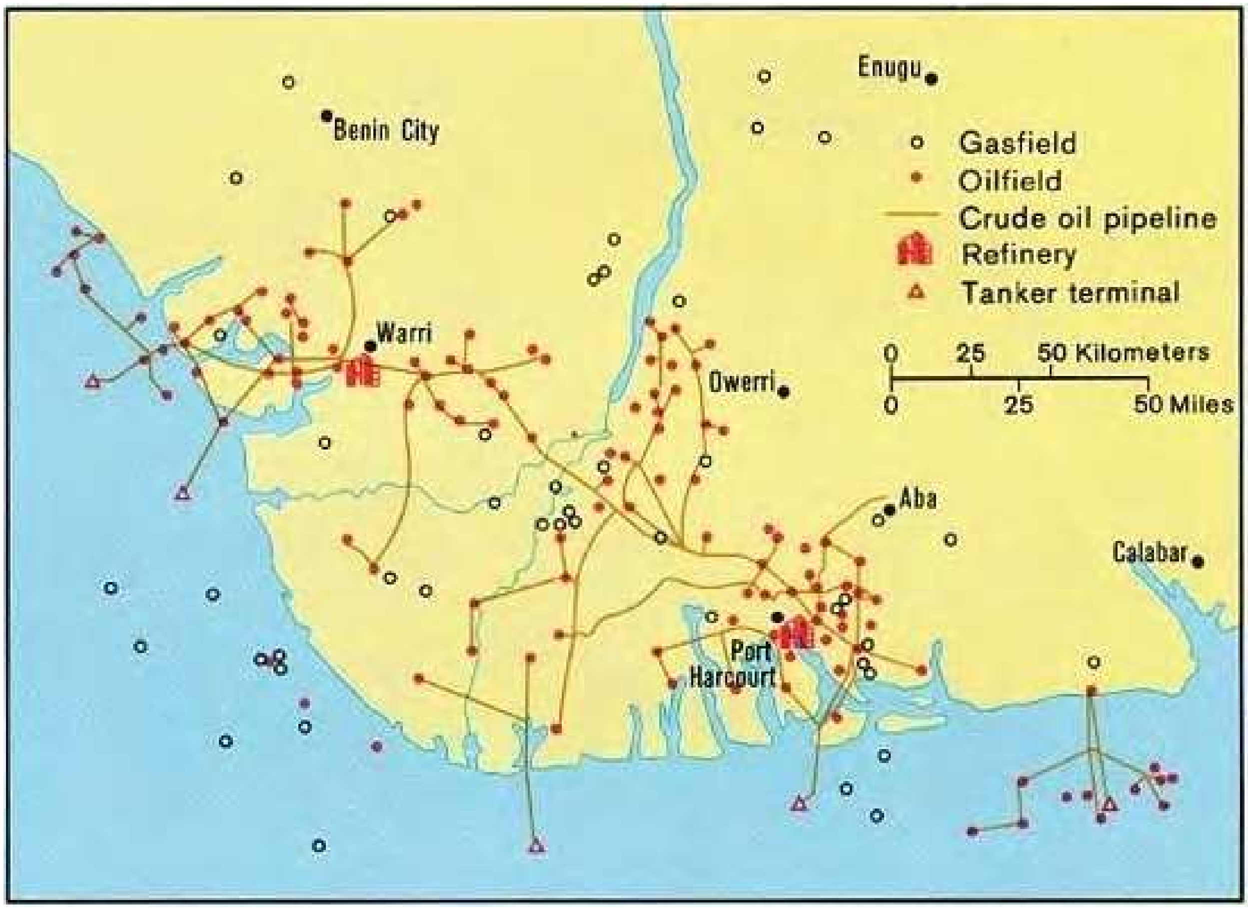


Fig. 2. Map of study area (Niger Delta)

5. Sources of ionizing radiation in the hydrocarbon industry

There are a number of sources for the ionizing radiation associated with the hydrocarbon industry. These include the earth's crust. The earth's crust is a natural source of oil and gas naturally occurring radioactive materials (NORM) as it contains the radionuclides ^{238}U and ^{232}Th. These radionuclides become mixed with the oil, gas and water in the process of oil exploration and exploitation. The radioactive decay chains of these naturally occurring parent radionuclides have very long half-lives and are ubiquitous in the earth's crust with activity concentrations that depend on the type of rock. The radioactive disintegration of ^{238}U and ^{232}Th produce several series of daughter radioisotopes of different elements and of different physical characteristics with respect to their half-lives, modes of decay, and types and energies of emitted radiation. A second source of NORM in the oil and gas industry is scale. Scales consist primarily of insoluble compounds of such elements like barium, calcium and strontium. These compounds precipitate from the produced water as a result of changes in temperature and pressure (IAEA, 2003). The radioactive substances found in scales are the radium isotopes (^{226}Ra and ^{228}Ra). Sulphate scales are the main types of scales in the oil and gas industry (OGP, 2008).

Sludge and scrapings are also sources of NORM in the hydrocarbon industry. Oil field sludge consists of dissolved solids which like scales precipitate from produced water due to variations in temperature and pressure. Generally, sludge is composed of oily, loose materials that may contain both silica compounds and a large amount of barium. The radionuclide found in sludge include radium, while ^{210}Pb and ^{210}Po are found in pipeline scrapings and in sludge that have accumulated in gas/oil separators and liquefied natural gas (LNG) storage tanks. Gas processing facilities are also another source of NORM. The radionuclide in this case is the radon gas.

In the Niger delta region of Nigeria the absence of infrastructural facilities for natural gas utilization has made gas flaring widespread in the region. As previously mentioned, about 50% of the natural gas is flared in the region thereby greatly contributing to the radon in the atmosphere of the region. Seawater injection systems also contain NORM, especially uranium. Seawater is used in the process of oil recovery from reservoirs and incidence of ionizing radiation due to this source is greatly increased in the case where a large volume of seawater is used (OGP, 2003). Incidence of ionizing radiation is further enhanced in the Niger delta of Nigeria as about 12% of the gas is re-injected into wells to improve oil recovery.

6. Effects of ionizing radiation

Radiation monitoring in the hydrocarbon region of Nigeria is important because of the health hazards and the environmental impact of ionizing radiation. Various health hazards of ionizing radiation have been documented. These include the following:

Erythema which is an increased redness of the skin as a result of capillary dilation.

Cancers: The skin is a radiosensitive part of the body and is also its most exposed part. Exposure to ionizing radiation leads to skin cancer. Also, various other kinds of cancers are linked to exposure to ionizing radiation. These include leukaemia, and cancers of the lung, stomach, oesophagus, bone, thyroid, and the brain and nervous system. Not all forms of cancer are traced to exposure to ionizing radiation.

Genetic Effects: Exposure of the reproductive cells to ionizing radiation can lead to miscarriage or genetic mutation. Genetic mutation affects the embryo causing deformity or death.

Sterility: Developing sperm cells known as gonads have very high radiosensitivity, exposure to ionizing radiation can therefore lead to sterility.

Cataracts: Opacities on the surface of the eye lens, called cataracts, result from the denaturing of the lens protein. One effect of ionizing radiation is the denaturing of the lens.

Atrophy of the Kidney: Exposure to ionizing radiation can lead to a condition known as atrophy of the kidney. In this case, the kidney and urinary tract waste or shrink with attendant loss of renal functions.

The level of damage experienced due to exposure to ionizing radiation is determined mainly by the radiation dose received and by such other factors as duration of exposure, nature of radiation and the sensitivity of the part of the body irradiated (ICRP, 1977, UNSCEAR, 1988). Radiation health hazards are dose-dependent. The overall effect of ionizing radiation in man is greatly enhanced when both radionuclide deposition and energy absorption by a specific organ or tissue occur together.

7. Ionizing radiation profile of the Niger Delta, Nigeria

Oil field development and gas exploitation activities have resulted in various forms of unsettling environmental activities in the Niger Delta region that have impacted the ecological, biophysical and socio-economic and political structure of the area (Abali, 2009).

Also, there is ample evidence globally that the hydrocarbon industry contributes to the elevation of the ionizing radiation of the areas where its operations are carried out.

The oil and gas industry, like the rest of the global community, places much emphasis on a safe work environment. Various indices may be adopted to assess what constitutes a safe and healthy work environment, among which is the incidence of certain levels of ionizing radiation in the given area. A study was conducted to evaluate the occupational ionizing radiation levels at 30 locations of oil and gas facilities in Ughelli in the Niger delta of Nigeria (Avwiri et al, 2009). The study was carried out during two time periods – during the production periods and during the off-production periods. Not unexpectedly, the study showed that radiation levels were higher during production periods than during the off-production periods (Fig. 3). The mean radiation levels workers in the oil fields were exposed to during both production and off-production periods are shown in Table 1. For example, the mean obtained for the radiation levels during the off-production periods had a range of 13.38±1.69μR/h (0.023±0.003mSv/wk) to 16.29±2.60μR/h (0.027±0.004mSv/wk) while the mean obtained for the radiation levels during the production periods had a range of 15.50± 1.65μR/h (0.026±0.003mSv/wk) to 19.14±3.16μR/h (0.32±0.005mS/wk). For the two periods under investigation, the Eriemu oil field had the highest radiation levels with a mean equivalent dose rate of 7.88±1.29μRh^{-1}, while the Kokori oil field had the highest percentage radiation deviation of 15.19%.

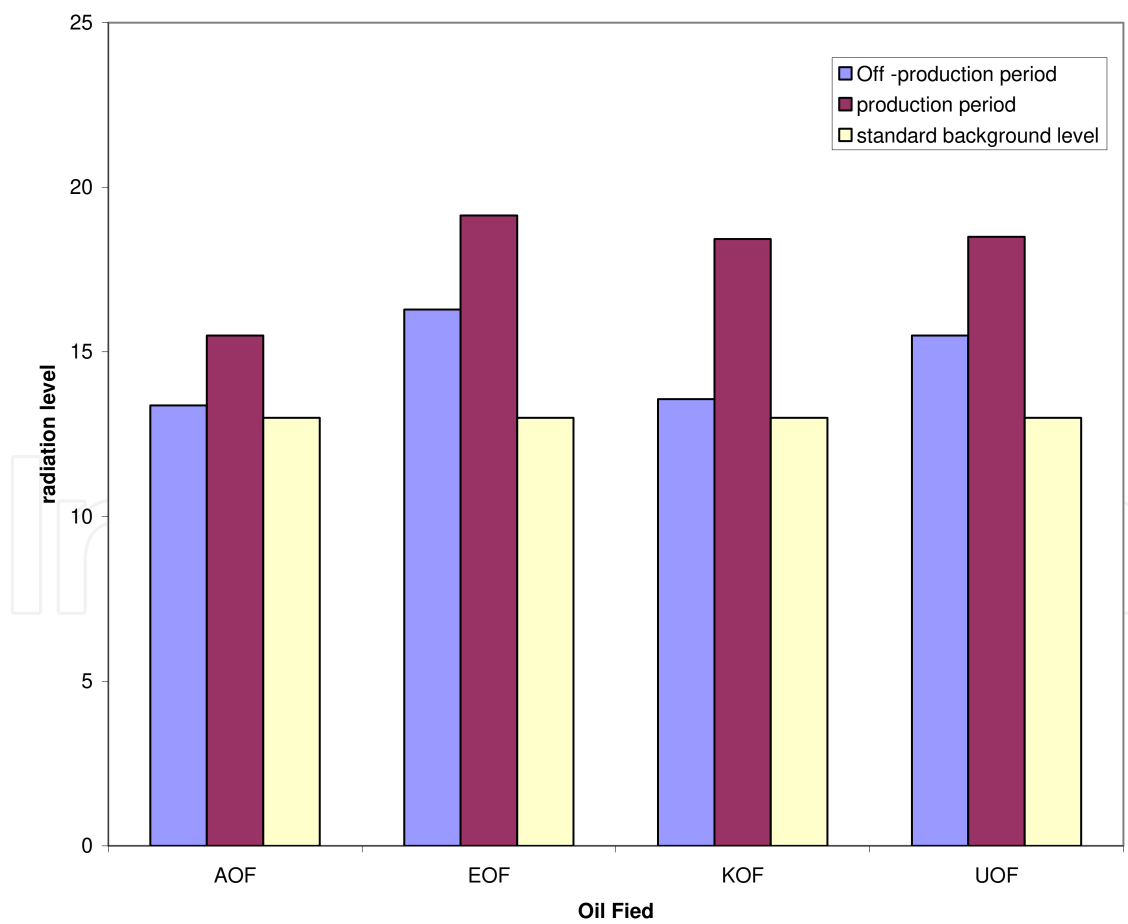


Fig. 3. Comparison of mean radiation levels (μR/h) in the fields with standard background level (Avwiri et al, 2009)

Field code	Surveyed oil and gas field	Mean radiation levels (μR/h)		Mean Deviation (%)	Mean dose equivalent rate (μSv/wk)
		Off - production	Production period		
AOF	Afiesere oil field	13.38 ±1.69	15.50±1.65	**7.34**	**6.43**±0.75
EOF	Eriemu oil field	16.29±2.60	19.14±3.16	**8.04**	**7.88**±1.29
KOF	Kokori oil field	13.57±1.80	18.43±2.68	**15.19**	**7.12**±0.99
UOF	Ughelli oil field	15.50±2.53	18.50±2.68	**8.82**	**7.57**±1.16
	MEAN	**14.69**±2.16	**17.89**±2.54	**9.85**	**7.25**±1.65

Table 1. Mean Exposure Rates in the Oil Fields.

We observe that though for both periods, the mean radiation levels are all within the safe radiation limit of 0.02mSv/wk as recommended by the UNSCEAR (1993) there is still a certain measure of occupational radiation health hazard in these locations for the following reasons:

1. The higher radiation levels during production periods compared to those during off-production periods show that the activities at the oil and gas facilities have led to the elevation of the radiation levels at the study locations. It further shows that the activities during the production periods contribute to higher occupational risk for the workers. Workers are therefore exposed to higher radiation risks during production periods and lower risks during off-production periods.
2. The observed disparity in the exposure rates between the production period and the off-production period was seen as implying that there was increased use of radionuclides, increased exposure to flowing crude oil (spillage) and gas flaring activities resulting in elevation of the ionizing radiation levels of the facilities and their immediate neighbourhoods (Avwiri et al, 2009).
3. The exposure rates at all the locations were generally higher than the standard background level of 13.0μR/hr (Fig. 3).
4. Very high exposure levels of 20μR/hr and above were common. The highest level of 26.00±0.5.1μR/h (0.044±0.009mSv/wk) was recorded at the Kokori oil field during production.
5. Even during off-production periods, high exposure levels were also recorded. For example, an exposure level of 22.00μR/h±2.1μR/h was obtained at the Eriemu natural gas compressor station vessel.
6. Generally, the radiation levels at the Natural Gas Compressor (NGC) facilities were found to be higher than the 0.02mSv/week recommended by the UNSCEAR (1993). The NGC facilities were therefore found to be the most unsafe work-environments as the highest radiation levels were obtained there. This may be attributed to the presence of radon at the facility as this radioactive gas is very much associated with the gas exploitation procedures of the hydrocarbon industry (OGP, 2008)
7. A previous study of the radiation around oil and gas facilities in Ughelli showed that for the oil fields the exposure dose rate had a mean range of 12.00± 0.lμRh (5.33±0.35μSv/wk) to 22.00±2.lμRh-1 (9.79±0.16) and 09.00±1.0 to 11.00±0.5μRh-1 in the host communities (Avwiri, et al., 2007)). Compared to the present investigations we observe that the radiation levels have increased appreciably.

A six-year impact assessment of ionizing radiation was published which reported the effect of oil spillage on the ionizing radiation profile of the oil spillage environment and the host communities in parts of Delta state (Agbalagba and Meindinyo, 2010). The study used a geographical positioning system (GPS) and a digilert nuclear radiation monitor. For the actual survey, 20 sites were chosen along with 6 host communities spread across the affected area and a control sample. The mean values obtained for the location ranged from 0.010 mRh^{-1} (0.532 mSv y^{-1}) to 0.019 mRh^{-1}(1.010mSv y^{-1}). In the area affected by oil spillage, the study gave a yearly exposure rate that ranged from 0.013±0.006 mRh^{-1}(0.692±0.080 $mSvy^{-1}$) to 0.016±0.005 mRh^{-1} (0.851±0.100 $mSvy^{-1}$); the values for the host communities ranged from 0.011 mRh^{-1}(0.585 $mSvy^{-1}$) to 0.015 mRh^{-1}(0.798 $mSvy^{-1}$). The exposure rate for the control was 0.010 mRh^{-1}(0.532 $mSvy^{-1}$).

The study established the impact of oil spillage on the radiation levels within the area and the host communities showing that the radiation levels of both the oil-spilled area and the host communities were elevated by the oil spillage. The radiation exposures were 55% and 33.3% respectively above the normal background level of 0.013 mRh^{-1}. Also, the mean equivalent dose rate for the study area although within the safe limit of 0.05 $mSvy^{-1}$ recommended by ICRP (1990) and NCRP (1993) was higher than the 0.0478 mSv/y normal background level.

Chad-Umoren and Briggs-Kamara (2010) assessed the ionizing radiation levels in parts of Rivers State, one of the states in the Niger delta region. The major thesis of that work was that since there is a near homogeneous distribution of oil and gas operations in the state, the radiation profile of the state will correlate with this, such that the state will exhibit a homogeneous radiation profile. The state was then delineated into three zones, namely, an upland college campus; a collection of rural communities and a group of industrial establishments forming the industrial zone. A Comparative analyses of the results for the three sub-environments showed that the highest dose equivalent of 1.332±0.076mSv/yr occurred in the industrial zone while the lowest value of 0.57±0.16mSv/yr was obtained in the rural riverine sub environment. The computed mean dose equivalent for the three zones also showed that the industrial sector had the highest mean value of 1.270±0.087mSv/yr, while the mean for the upland college campus environment was 0.745±0.085mSv/yr with the rural riverine communities having the lowest mean dose equivalent of 0.690± 0.170mSv/yr.

It is to be observed that the very high exposure rate of 0.0168mR/hr was recorded in this study and that it was obtained in an oil-activity-related environment.

This study revealed the following: Firstly, anthropogenic activities have great impact on the radiation levels of the environment. Secondly, the industrial environment of the state contributes the most to the radiation levels of the state (Tables 2, 3 and 4). Thirdly, the dose equivalent for the different components of the industrial environment are all higher than the European Council for Nuclear Research (CERN) recommended value of 1.0mSv/yr for the general population who are not engaged in nuclear radiation related occupations (CERN, 1995). Fourthly, the dose equivalents obtained for the other two environments are within the CERN regulations.

A national energy policy articulated by the national government of the federation of Nigeria encourages the efficient utilization of the nation's abundant oil and gas reserves (NEP, 2003). Recently the impact of this energy policy on the radiation profile of Ogba/Egbema/Ndoni, a Local Government Area in the central Niger delta state of Rivers state was studied (Ononugbo et al, 2011). The study area was divided into six zones (Table 5). To ensure that the original environmental characteristics of the samples were not tampered with, an *in situ* approach of background radiation measurement was used. The

Station	Name
1	Port Harcourt Refinery Company (PHRC) PHRC Junction, Alesa
2	Nigeria Ports Authority, Onne NAFCON(Fertilizer company), Onne
3	Bori/Onne Junction
4	Rumuokoro Junction
5	Choba (Wilbros)
6	Nkporlu Village
7	Arker Base
8	Mobil Area.

Table 2. Stations for experiment (Industrial environment) (Avwiri and Ebeniro, 2002)

Station	Counter	*mR/hr	S	μ	T	Tc	Remarks
1	3	0.0149	0.0008	0.0144	1.98	2.26	t<tc
	2	0.0154	0.0006	0.0144	5.27	2.26	t>tc
	1	0.0128	0.0008	0.0144	-6.32	-2.26	t<tc
2	3	0.0148	0.0008	0.0143	1.93	2.26	t<tc
	2	0.0159	0.0007	0.0143	7.23	2.26	t>tc
	1	0.0122	0.0010	0.0143	-6.04	2.26	t<tc
3	3	0.0145	0.0006	0.0146	-0.53	2.26	t<tc
	2	0.0156	0.0011	0.0146	6.04	-2.26	t>tc
	1	0.0138	0.0022	0.0146	-1.15	-2.26	t>tc
4	3	0.0151	0.0007	0.0145	2.71	2.26	t>tc
	2	0.0159	0.0011	0.0145	4.02	2.26	t>tc
	1	0.0124	0.0007	0.0145	-4.50	-2.26	t<tc
5	3	0.0150	0.0006	0.0143	3.69	2.26	t>tc
	2	0.0150	0.0006	0.0143	3.69	2.26	t>c
	1	0.0121	0.0007	0.0143	-9.94	-2.26	t<tc
6	3	0.0148	0.0009	0.0147	0.032	2.26	t<tc
	2	0.0160	0.0008	0.0147	4.30	2.26	t>tc
	1	0.0136	0.0019	0.0147	-2.00	-2.26	t>tc
7	3	0.0147	0.0003	0.0147	-0.109	-2.26	t>tc
	2	0.0155	0.0008	0.0147	3.35	2.26	t>tc
	1	0.0138	0.0006	0.0147	-4.688	-2.26	t<tc
8	3	0.0141	0.0009	0.0144	0.94	-2.26	t>tc
	2	0.0155	0.0012	0.0144	3.00	2.26	t>tc
	1	0.0135	0.0015	0.0144	-1.83	-2.26	t>tc
9	3	0.0130	0.0006	0.0140	-5.47	-2.26	t<tc
	2	0.0154	0.0006	0.0140	7.79	2.26	t>tc
	1	0.0135	0.0004	0.0140	-3.25	-2.26	t<tc
10	3	0.0155	0.0007	0.0152	1.26	2.26	t<tc
	2	0.0168	0.0013	0.0152	3.86	2.26	t>tc
	1	0.0132	0.0006	0.0152	-10.89	-2.26	t<tc

Table 3. T-test for stations at 5% confidence level and (n-1) degrees of freedom showing mean counter rate (*), mean background radiation (μ), standard deviation(s), computed t and critical t (tc) with sample size (n) of 10 (Industrial environment) (Avwiri and Ebeniro, 2002)

Station	Mean exposure rate, R (mR/hr)	Dose equivalent, D (mSv/yr)
1	0.0144±0.0007	1.261±0.064
2	0.0143±0.0008	1.253±0.073
3	0.0146±0.0013	1.279±0.114
4	0.0145±0.0008	1.270±0.073
5	0.0143±0.0019	1.253±0.166
6	0.0147±0.0012	1.288±0.105
7	0.0147±0.0006	1.288±0.053
8	0.0144±0.0012	1.261±0.105
9	0.0140±0.0005	1.226±0.044
10	0.0152±0.0009	1.332±0.076

Table 4. Dose equivalent, D computed for the data of Table 3 (Industrial environment) (Avwiri and Ebeniro, 2002; Chad-Umoren and Briggs-Kamara, 2010)

study used a digilert 50 and a digilert 100 nuclear radiation monitoring meters containing a Geiger-Muller tube capable of detecting α, β, γ and x-rays within the temperature range of -10^{0}C to 50^{0}C, alongside a geographical positioning system (GPS) which was used to measure the precise location of sampling. The survey was carried out between the hours of 1300 and 1600 hours, because the exposure rate meter has a maximum response to environmental radiation within these hours (Louis *et al*, 2005). At each of the selected sites and within the host communities four readings were taken at intervals of 5 minutes and the average value determined. The tube of the radiation meter was held at a standard height of 1.0m above the ground with its window facing first the oil installations and then vertically downwards (Chad-Umoren *et al*, 2006). A ^{137}Cs source of specific energy was used to calibrate the instrument to read accurately in Roentgens. Estimate of the whole body equivalent dose rate was done using the National Council on Radiation Protection and measurements (NCRP, 1993) recommendation:

$$1\text{mRh}^{-1}=(0.96\times24\times365/100)\text{mSvy}^{-1} \quad (1)$$

Table 5 compares the mean radiation exposure rates for the hydrocarbon industry facilities and the mean radiation exposure rates for the host communities. The lowest mean radiation exposure rate of 0.014mRh^{-1} was obtained at Obite/Ogbogu. This low level may be attributed to the concrete shielding of the gas plant in the area and the distance of the host community from the Idu flow station (about 2km). For the surveyed oil and gas facility locations, the highest mean exposure rate of 0.018±0.002mRh^{-1} was obtained at the gas plant; while for the host communities, the highest mean exposure rate of 0.017±0.001mRh^{-1} was recorded in Ebocha and Obrikom communities of zones A and B. This value is well above the mean field/site radiation exposure level. The percentage exposure rate difference is minimum at the treatment plant and maximum at the gas turbine in Obrikom/Omoku.

At location 5 of zone C, a high exposure rate of 0.034mRhr^{-1} was recorded. This could be because of both the presence of sharp sand (asphalt) along the river bank and the industrial waste discharged into the river.

A comparison of the measured radiation levels for the six zones with the normal background level (Fig. 4) shows that the computed mean effective equivalent dose rate for the locations in all the six zones are above the dose limit of 1mSvyr^{-1} for the general public and far below the dose limit of 20mSvyr^{-1} for radiological workers as recommended by the

Area Code	Industrial Site Surveyed	Host community	Mean Site Radiation levels (mRh^{-1})	Mean Host Community Radiation levels (mRh^{-1})
A	Ebocha Oil Gathering Center	Ebocha/Mgbede	0.016 ± 0.001	0.017 ± 0.001
B	OB/OB Gas Plant	Obrikom/ Ndoni	0.016 ± 0.001	0.017 ± 0.001
C	Gas Turbine	Obrikom /Omoku	0.018 ± 0.002	0.016 ± 0.003
D	Treatment plant (Arrival Manifold)	Obrikom /Ebegoro	0.014 ± 0.001	0.014 ± 0.001
E	Obite Gas Plant	Obite /Ogbogu	0.015 ± 0.001	0.014 ± 0.001
F	Idu Flow Station	Idu /Obagi	0.016 ± 0.001	0.015 ± 0.001

Table 5. Comparison of Exposure rate at Industrial sites and Host Communities (Ononugbo et al, 2011)

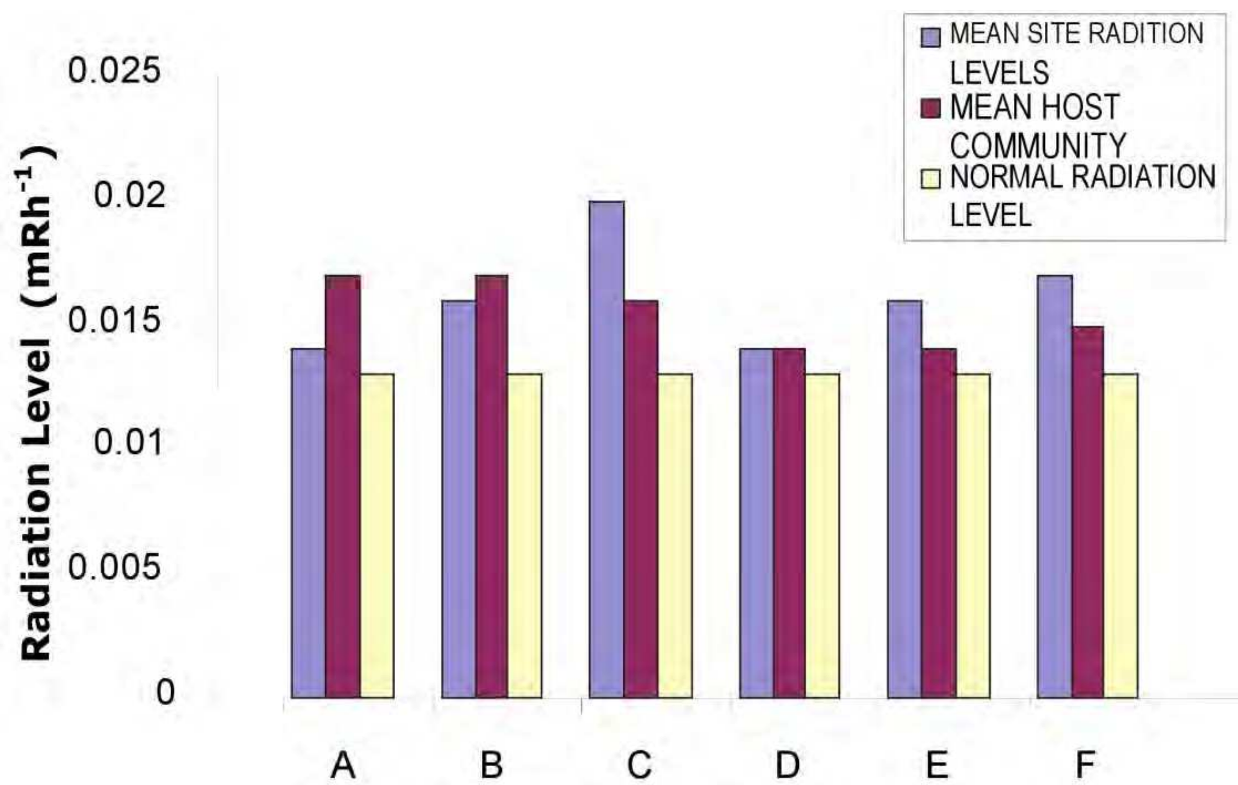


Fig. 4. Comparison of Measured Mean Radiation Levels with Normal Background Level (Ononugbo et al, 2011)

International Commission on Radiological Protection (ICRP, 1990). This indicates that while those exposed occupationally are safe, members of the host communities are not.

The results also show that although the values are within the range of values previously reported for the Niger Delta region (Arogunjo *et al*, 2004; Agbalagba and Avwiri, 2008 and Chad-Umoren and Briggs-Kamara, 2010), the radiation exposure rate for 71.7% of the sampled area (43 locations) exceeded the accepted ICRP background level of 0.013mRhr^{-1}.

S/N	Oil and Gas Facilities	Flow station installation radiation levels (μRh^{-1})					
		Afiesere Delta	Ughelli West Delta	Etelebou Bayelsa	Kolo-Creek Bayelsa	Adibawa Rivers	Egbema Rivers
1	Flow station entrance	08.00± 0.70	14.00± 2.30	12.00± 1.00	09.00± 1.10	19.00± 1.10	13.00± 1.10
2	Manifold	15.00± 2.00	19.00± 3.00	19.00± 2.80	12.00± 0.90	17.00± 2.20	16.00± 2.10
3	Flare monitoring meter units	12.00± 0.60	15.00± 2.10	16.00± 1.50	16.00± 1.00	16.00± 1.40	15.00± 2.20
4	Flare knock-out drum/vessel	14.00± 1.70	23.00± 4.20	18.00± 2.10	14.00± 1.60	25.00± 4.20	24.00± 3.20
5	Stack gas vent	15.00± 1.00	15.00± 1.00	21.00± 3.70	13.00± 0.80	19.00± 2.00	22.00± 3.20
6	Flare stack pathway	11.00± 0.80	17.00± 3.20	17.00± 1.80	24.00± 4.3.10	16.00± 2.20	17.00± 2.50
7	Flare stack point	19.00± 3.20	14.00± 1.40	14.00± 1.00	17.00± 2.10	14.00± 1.40	21.00± 3.60
8	Inflow delivery crude oil pipes	18.00± 1.60	19.00± 2.60	17.00± 3.00	24.00± 4.20	20.00± 2.00	21.00± 3.10
9	Inflow gas delivery pipes	15.00± 3.00	20.00± 4.00	13.00± 2.00	22.00± 3.00	20.00± 3.40	18.00± 2.40
10	Associate gas control meter	15.00± 2.00	20.00± 1.80	16.00± 3.10	20.00± 3.70	14.00± 0.60	19.00± 3.00
11	Natural gas compressor station (NGC)	21.00± 2.40	22.00± 2.10	Nil	Nil	Nil	Nil
	MEAN	**14.82± 1.74**	**18.00± 2.54**	**16.30± 2.20**	**17.10± 2.15**	**18.00± 2.02**	**18.60± 2.64**
Mean Rate	**Dose equivalent (μSv/wk)**	**6.70± 0.78**	**8.01± 1.13**	**7.25± 0.98**	**7.61± 0.96**	**80.01± 0.90**	**8.28± 1.17**

Table 6. Facilities exposure rate (Agbalagba et al, 2011)

A recent survey studied the gamma radiation profile of oil and gas facilities in six selected flow stations in the Niger delta region (Agbalagba et al, 2011). Of the different types of ionizing radiations, gamma rays are the most penetrating and therefore very hazardous. They emanate from radionuclides containing radon and may be ingested or inhaled by personnel in the course of routine repairs and maintenance of oil facilities. When inhalation occurs, the dust particles and aerosols containing radon become attached to the lungs so that the presence of the gamma rays emitted in the decay increases the risk of lung cancer and other hazards such as eye cataracts and mental problems to personnel and host communities (Laogun et. al., 2006).

The results are shown in Tables 6 and 7. The radiation levels for the facilities (Table 6) range from 08.00±0.70μRh^{-1} in Afiesere flow station entrance to 25.00±4.20μR^{-1} in Adibawa flare knockout vessel. The high value at the Adibawa knockout vessel can be attributed to the spill of associated crude and the exposure of the environment to effluent. The mean exposure rate for the flow stations range from 14.82±1.74μRh^{-1} (6.70±0.78μSv/wk) at Afiesere flow station to 18.60±2.64μRh^{-1} (8.28±1.17μSv/wk) at Egbema flow station, with field mean radiation value of 17.14±2.22μRh^{-1}. The high radiation levels recorded at the natural gas compressor stations (NGC) at Afiesere and Ughelli West flow stations may be attributed to the high concentration of radon in the natural gas and gas production facilities.

Table 7 compares the radiation exposure rate for both the flow stations and the host communities. The lowest radiation exposure rate of 10.00±0.70μRh^{-1} was obtained at Joinkrama 4 in Rivers State. This low radiation level may be attributed to the geology (underlying rock) of the area and to the distance of the host community from the flow station (~2.5km) which is the farthest among the six host communities. The highest average exposure rate (21.00±2.10μRh^{-1}) was obtained in Emeregha community in Afiesere field. This value is much higher than the mean field radiation exposure level.

S/N	Oil field/flow station	Host community	Mean fields Radiation levels μRh^{-1}	Mean Host community Radiation level μRh^{-1}	Exposure rate diff (%)
1	Afiesere	Emeragha	14.82.±1.74	21.00±2.10	17.3
2	Ughelli west	Ekakpamre	18.00±2.54	17.00±2.00	2.9
3	Etelebou	Nedugo	16.30±2.20	15.00±1.40	4.2
4	Kolo-creek	Imirigin	17.10±2.15	18.00±1.60	2.6
5	Adibawa	Joinkrama 4	18.00±2.02	10.00±0.70	28.6
6	Egbema	Egbema	18.60±2.64	14.00±1.10	14.1

Table 7. Comparison of Flow station and Host Communities (Agbalagba et al, 2011)

The presence of the radioactive gas, radon which is produced by the radioactive disintegration of radium–226, may be responsible for the variation of the radiation levels within the facilities. This is so because radon is known to be present in crude oil and gas products (IAEA, 2003). The dispersal of the gas is also favoured by wind direction at the point of liberation.

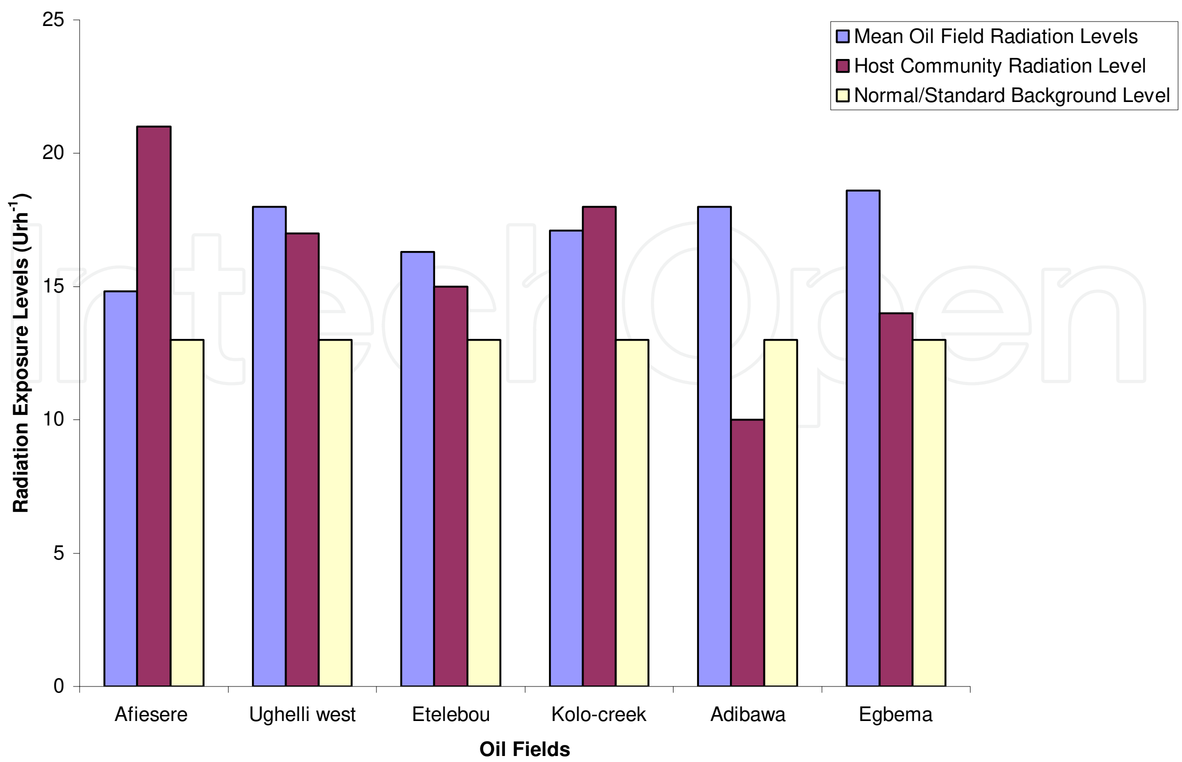


Fig. 5. Comparison of Mean Oil Fields and Host Communities Radiation Levels with Normal background Radiation Level (Agbalagba et al, 2011)

Fig.5 is a comparison of the mean radiation levels for the oil fields and host communities with the normal background ionizing radiation level. Overall, the results show that in all the six flow stations and their host communities except Joinkrama 4, the exposure rates exceed both the standard background levels and values reported previously by Ebong and Alagoa (1992a); Avwiri and Ebeniro (1998), but are in agreement with results reported in similar environments (Arogunjo et al., 2004; Laogun et al., 2006; Agbalagba et al., 2007). The differences in the exposure rates between host communities and flow stations can be attributed to the input materials and output substances (effluents) associated with the activities of the operating companies and dilution of radon as it transits to the host communities. The only exception, the Emeragha community, may be due to the existence of oil wells (wells 7, 10 and 14) within the community which may have enhanced radon concentration and hence the radiation level in the community.
Furthermore, the radiation levels recorded for gas flare facilities and natural gas compressor stations are fairly higher than those for other facilities. This is in agreement with the study of occupational radiation patterns during production and off-production periods (Avwiri et al, 2010). Also, the observation implies the presence of a high concentration of radon gas and heavy metals normally associated with natural and associated gas (Arogunjo et al. 2004; Laogun et al., 2006). However, this study indicates that the radon concentrations in the natural gas at these facilities in the region are low when compared to those obtained in countries like the USA, Great Britain and Canada (Laogun et al., 2006) where radon concentrations (radiation levels) pose enormous environmental challenges requiring government legislation for the control of naturally occurring radiation material (NORM) contamination in their petroleum industries.

The results of the survey did not indicate that there is in the short term the possibility of any health hazard either for the flow station attendants (staff) or the residents of the host communities since the highest average radiation exposure levels of 18.60±2.64μRh^{-1} (8.28±1.17μSv/wk) recorded at Egbema flow station and 21.00±2.10μRh^{-1}(9.35±0.93μSv/wk) obtained at Emeragha community are within the UNSCEAR recommended permissible limit of 200μSv/wk for public health and safety (UNSCEAR, 1993). However, the possibility of future health complications for the staff and host communities does exist as a result of prolonged cumulative dose intake from both direct and indirect radionuclides. Also, it is observed from Fig. 5 that the mean radiation exposure in all the oilfields is higher than the normal background which implies that the oil exploration and gas exploitation activities have impacted significantly on the background ionizing radiation levels of the area. According to Agbalagba et al (2011), this impact can be attributed to the underlying crude oil and gas being contaminated by radionuclide bearing rocks/elements (uranium, thorium and radium) which when drilled to the surface and exposed to the terrestrial environment at the oil installations, releases radon gas and other heavy metals which enhances the background levels of the area and other input materials."

S/N	SAMPLED AREA	GEOGRAPHICAL LOCATION	RADIATION LEVEL mRh$^{-!}$		AVE. RAD. VALUE mRh$^{-!}$	EQ. DOSE mSvy^{-1}
			RAD 50	RAD 100		
1	Crude Flow Pipe	NO5 32.297′ E005 53.780′	0.019	0.018	0.0185±0.004	0.9843±0.32
2	Natural Gas Compressor	NO5 26.021′ E005 52.940	0.025′	0.019	0.0220±0.008	1.170±0.43
3	Flow station entrance	NO5 26..057′ E005 52.926′	0.017	0.018	0.01759±0.007	0.931±0.37
4	Well 7	NO5 25.918′ E005 53.014′	0.021	0.024	0.2230±0.010	1.186±0.53
5	Pegging Manifold	N05 26.062′ E005 52.901′′	0.019	0.021	0.020±0.008	1.064±0.43
6	Well 10	N05 25.671′ E005 52.930′	0.016	0.018	0.0170±0.006	0.9041±0.32
7	Flare Stack Site	N05 26.141 E005 52.653	0.024	0.025	0.0245±0.011	1.303±0.58
8	Well 5	NO5 25.701′ E005 52.608′	0.018	0.020	0.0190±0.009	1.011±0.48
9	Otorogu Gas Plant	NO5 25.701′ E005 52.608′	0.028	0.034	0.0310±0.010	1.649±0.53
10	***Otujeremi Town***	***NO5 25.865′ E005 52.567′***	***0.022***	***0.020***	***0.0210±0.007***	***1.117±0.37***
	MEAN FIELD LEVELS				**0.0213±0.008**	**1.134±0.44**

Table 8. Otorogu Oil and Gas Field

Tables 8 - 11 give the results of ionizing radiation monitoring for oil and gas fields located at Otorogu, Evwreni, Oweh, Uzere East and West, while Table 12 compares the ionizing radiation profile of the study fields with those of the host communities (Agbalagba et al, 2011). The radiation status of various areas and parts of the oil and gas facilities are given such as the crude flow pipe, flow station, gas plants, crude oil control valve, manifold, oil wells and host communities. In each specific area two Radalerts were used – Radalert 50 and Radalert 100 and the average radiation level computed.

S/N	SAMPLED AREA	GEOGRAPHICAL LOCATION	RADIATION LEVEL mRh^{-1}		AVE. RAD. VALUE mRh^{-1}	EQ. DOSE $mSvy^{-1}$
			RAD 50	RAD 100		
1	Camp site	NO5′ 22.720′ E006 02.962′	0.011	0.011	0.0110± 0.003	0.585± 0.16
2.	Well 13	NO5′ 22.615′ E006′ 02 640′	0.015	0.014	0.0145± 0.005	0.771± 0.27
3	Manifold	NO5′ 22.405′ E006′ 02.405′	0.019	0.013	0.0160± 0.006	0.851± 0.32
4	Well 1	N05′ 22.327′ E006′ 02.410′	0.017	0.014	0.055± 0.005	0.825± 0.27
5	Flow station Gate	N05′ 22.445′ E006. 02.470′	0.015	0.016	0.0155± 0.006	0.825± 0.32
6	L & S Tanga crude flow pipe	N05′ 22.428′ E006″ 02 500	0.015	0.014	0.0145± 0.005	0.771± 0.27
7	Gas vent (knockout drum)	N05′ 22.432′ E006 22.482′	0.020	0.022	0.0210± 0.009	1.117± 0.48
8	Flare stock site	N05″ 22.361′ E006″ 02.451′	0.021	0.018	0.0195± 0.008	1.0371± 0.83
9	Well 11	N05″ 22 .394′ E006′ 02.439′	0.014	0.014	0.0140± 0.005	0.771± 0.27
10	***Evwreni Community***	***N05′ 24.243′ E006″ 03.451′***	***0.017***	***0.014***	***0.0155± 0.007***	***0.8258± 0.32***
	MEAN FIELD LEVEL				**0.0160± 0.006**	**0.839± 0.34**

Table 9. Evwreni Oil and Gas Field

S/N	SAMPLED AREA	GEOGRAPHICAL LOCATION	RADIATION LEVEL mRh-1		AVE. RAD. VALUE mRh-1	EQ. DOSE mSvy-1
			RAD 50	RAD 100		
1	Flow Station Gate	NO5′ 29.271′ E006 08.101′	0.016	0.012	0.0140±0.005	0.745±0.27
2.	Crude oil control valve	NO5′ 08.101′ E006′ 08′	0.019	0.019	0.0190± 0.007	1.011±0.37
3	Gas vent (knockout drum)	NO5′ 29.289′ E006′ 08.201′	0.017	0.016	0.0165±0.006	0.878±0.32
4	Flare stack site	N05′ 29.304′ E006′ 08.244′	0.016	0.018	0.017±0.005	0.904±0.27
5	NGC Station	N05′ 29.216′ E006. 08.132′	0.022	0.020	0.0210±0.008	1.117±0.43
6	L & S tango Crude flow pipe	N05′ 29.285′ E006″ 28 185′	0.016	0.014	0.0150± 0.006	0.798±0.32
7	Manifold	N05′ 28.185′ E006 07.720′	0.019	0.018	0.01850±0.008	0.984±0.43
8	Well 12	N05″ 29.666′ E006″ 06.567′	0.020	0.018	0.0190±0.007	1.011±0.37
9	Well 2	N05″ 29 .219′ E006′ 08.128′	0.018	0.023	0.0205±0.010	1.091±0.53
10	***Otor-Oweh community***	***N05′ 29.614′ E006″ 06.248′***	***0.012***	***0.014***	***0.0130±0.005***	***0.692±0.27***
	MEAN FIELD LEVEL				**0.0178±0.007**	**0.949±0.37**

Table 10. Oweh Oil and Gas Field

S/N	SAMPLED AREA	GEOGRAPHICAL LOCATION	RADIATION LEVEL mRh-1		AVE. RAD VALUE mRh-1	EQ. DOSE mSvy-1
			RAD 50	RAD 100		
1	Manifold	NO5′ 20.080′ E006 14.865 ′	0.016	0.015	0.0155±0.006	0.525±0.32
2.	Buster station	NO5′ 20.162′ E006′ 14 .781′′	0.017	0.014	0.0155± 0.005	0.825±0.27
3	NGC Station	NO5′ 19.751′ E006′ 14.762′	0.016	0.019	0.0175±0.006	0.931±0.32
4	Flow station Gate	N05′ 19.627′ E006′ 14.655′	0.027	0.028	0.0275±0.013	1.463±0.69
5	L & S Tango crude flow pipe	N05′ 19.167′ E006. 14.642′	0.022	0.024	0.230±0.010	1.224±0.53
6	Flare knock out down	N05′ 19.601′ E006″ 14. 633′	0.020	0.018	0.01900± 0.008	1.011±0.43
7	Flare stack site	N05′ 19.584′ E006′ 14.566′	0.017	0.021	0.0190±0.007	1.011±0.37
8	Well 6	N05″ 19.251′ E006″ 15.960′	0.019	0.023	0.0205±0.009	1.277±0.64
9	Well 2	N05″ 19 .421′ E006′ 15.862′	0.022	0.026	0.0240±0.012	1.277±0.64
10	***Uzere community***	***N05′ 20.268′ E006″ 14.338′***	***0.016***	***0.019***	***0.0175±0.007***	***0.931±0.27***
	MEAN FIELD LEVEL				**0.0202±0.008**	**1.075±0.45**

Table 11. Uzere East and West Oil and Gas Field

Area Code	Oil and Gas Field	Host Community	Mean field dose rate (mSvy-1)	Host Community dose rate (mSvy-1)	Difference (%)
OUT	Otorugu	Otujeremi	1.134±0.31	1.117±0.37	1.51
EVN	Evwreni	Evwreni	0.839±0.34	0.612±0.16	22.70
OWT	Oweh	Otoweh	0.949±0.37	0.692±0.27	37.14
OLO	Olomoro-Oleh	Olomoro	0.943±0.37	0.931±0.27	1.29
UZE	Uzere West & East	Uzere	1.075±0.45	0.931±0.37	14.4

Table 12. Comparison of Studies fields and Host Communities Radiation Data

Table 12 shows that the highest mean dose rate for the oil fields, 1.134±0.31mSvy^{-1} was recorded at the Otorugu field and its host community, Otujeremi, recorded the highest dose rate, 1.117±0.37mSvy^{-1}, for the host communities. It would appear that the preponderance of gas operations in Otorugu as compared to the other fields has resulted in an increased release of radon gas into the atmosphere over the oilfield and its host community leading to significant impact on the radiation level of the oilfield and its host community.

8. Water and soil analyses

The Niger delta has a plethora of interconnected underground and surface waterways and this can have some impact on the dispersal of ionizing radiation in the environment as they have the potential to transport particulate radioactive matter. Sediments from different water bodies and industrial effluents discharged into the water bodies are transported from location to location. Furthermore, evaluating the water in the region for radioactivity becomes especially important as the water from creeks, streams and rivers in much of the region is also used for such activities as washing, bathing, cooking and drinking! Through any of this means radionuclide ingestion and consequent radiation contamination of the populace can attend epidemic proportions. Another route for radionuclide ingestion by the human population is through the consumption by man of fish and other sea foods that have been contaminated by radiation.

A study conducted in Delta state, another Nigeria Niger delta state, using Exploranium - The-Identifier GR-135 model, assessed the natural radioactivity concentration in river Forcados (Avwiri et al, 2008). 20 water samples were collected from 20 different locations separated a distance of 100m from each other. The study identified three radionuclides, namely ^{40}K, ^{226}Ra and ^{232}Th with respective average specific activity of 13.94$\pm$1.97Bq/l, 12.80$\pm$2.84Bq/l and 34.62$\pm$3.71Bq/l. The mean absorbed dose rates and dose equivalent were computed to be 9.90$\pm$1.61nGy/h and 0.084$\pm$0.003mSv/y respectively. The survey did not indicate any radionuclide concentration gradient as the values in the survey were found to be randomly distributed. This can be attributed to the water transportation mechanism and effluent discharge.

Also, the results show low concentration of the identified radionuclides in the water and may therefore not pose any radiological effects on the populace that use the water from this river. Furthermore, the values are comparable to previous surveys within the Niger delta region (Arogunjo et al, 2004), however, they are higher than the value of 1.2mBq/l (^{226}Ra) reported for Lake Ontario (Baweja et al, 1987) and 28 x 10^{-6} Bq/l (^{232}Th) for Lake Michigan. This disparity can be attributed to the activities of the hydrocarbon industry in the Niger delta.

In a survey of the gross alpha and beta radionuclide activity in the Okpare Creek in Delta State, Nigeria, Avwiri and Agbalagba (2007) classified the creek into three zones and reported average alpha activities in the classified zones as 1.003±0.097, 4.261 ± 0.109 and 10.296±0.489Bql^{-1} respectively, and the beta activities as 0.129±0.100, 0.523+0.003 and 0.793+ 0.010Bql^{-1} respectively. These values are far above the 0.1Bq/l for alpha and 1.0Bq/l for beta WHO maximum recommended level for screening for drinking water (WHO, 2003). A previous study by Avwiri et al (2005) assessed the radionuclide contents of soil, sediments and water in Aba River in the Niger delta state of Abia state. In addition to these, the radionuclide content of the fish in the river was also evaluated. The work employed a rigorously calibrated sodium iodide (NaI) detector. The radionuclides identified were ^{226}Ra, ^{228}Ra and ^{40}K for all three study samples. For the soil samples the respective average specific activity levels obtained were 4.73±0.71Bq/kg, 4.26±0.9Bq/kg, and 118.75±10.54Bq/kg. The activity levels of the radionuclides for the water samples were 3.34±0.43Bq/l, 3.69±0.17Bq/l and 111.39±10.04Bq/l respectively. In the case of the sediments the study gave 11.56±2.35Bq/kg, 17.50±1.77Bq/kg and 253.42±21.10 respectively. And for the catfish from the river, the activity levels were 19.14±4.33Bq/kg, 22.58± 5.58Bq/kg and 63.42±14.09Bq/kg respectively. These results show significantly higher concentrations compared to a previous study (Jibiri et al, 1999). The operations of the Industrial Zone in Aba account for these significantly high values as they discharge their effluents directly into the river. An analogous study to assess the radiological impact of the petrochemical industry on the Aleto Eleme River showed a significant elevation of the ionizing radiation levels at the point of effluent discharge into the river (Avwiri and Tchokossa, 2006).

A study carried out to assess the level of natural radionuclides in borehole water in some selected wells in Port Harcourt, Rivers State showed that the mean specific activity of the resulting annual effective doses for ^{226}Ra, ^{228}Ra and ^{40}K were 3.51±2.22, 2.04 ± 0.29 at 23.03 ±4.37 and 0.36 ± 0.12, 0.51± 0.02 and 0.05 ±0.01mSy/y respectively (Avwiri et al, 2006). The results of this survey are within the range obtained elsewhere. Generally, public places showed the highest activity concentration due to poor sanitation.

Waste management in urban centres is important for environmental health. In many parts of the Niger delta region, wastes are sometimes collected and heaped up and no further action taken until they are scattered again by wind; disposed of indiscriminately or they may be disposed of in landfills. Landfills are openings in the soil used for waste disposal. They could be purpose-made or an abandoned pit or quarry. Many of the landfills in the Niger delta region are usually not differentiated and therefore will hold a mixture of different types of wastes, including those from the hydrocarbon industry. Landfills are an important source of groundwater pollution and may also result in the elevation of the ionizing radiation profile of the environment due to its radionuclide content. One survey conducted in the city of Port Harcourt, Rivers State, assessed the radionuclide content, the ionizing radiation level and associated dose rates of a landfill around the Eliozu area of the city (Avwiri et al, 2011). The Eliozu landfill is composed of different types of wastes including industrial wastes, chemical wastes, medical wastes, scraps, metals and other debris.

10 samples each of soil and water were collected from different parts of the landfill and analyzed for their radioactivity and radionuclide content using the gamma-ray spectrometer NaI (Tl) detector system. The results are shown in Table 13 for the soil samples and in Table 14 for the water samples.

The radionuclides found in both the soil and water samples were ^{232}Th, ^{238}U and ^{40}K. The study reported that for the soil samples, the mean activity concentration were 27.41 ± 9.97 Bq/kg for ^{238}U, 19.27 ± 8.14 Bq/kg for ^{232}Th and 326.08 ± 66.74 Bq/kg for ^{40}K (Table 7). And for the water samples, the mean activity concentration were 7.92 ± 2.69 Bq/l, 6.96 ± 2.37 Bq/l and 24.77 ± 8.33 Bq/l for ^{238}U, ^{232}Th, ^{40}K respectively (Table 8). The calculated absorbed dose rates for the soil had a range of 23.53 $nGy.h^{-1}$ to 50.39 $nGy.h^{-1}$ and a mean of 38.17 ±12.45 $nGy.h^{-1}$ while for the water the range was 6.62 $nGy.h^{-1}$ to 10.71 $nGy.h^{-1}$ with a mean of 9.03±3.07 $nGy.h^{-1}$. The mean absorbed dose rate for the area is lower than the world's average of 55 $nGy.h^{-1}$for soil. It should however be observed that the upper limit of 50.39 $nGy.h^{-1}$ is quite close to the world average.

		Soil (Bq/kg)				
S/No	**Sample**	**K-40**	**U-238 (Ra-226)**	**Th-232 (Ra-228)**	**Absorbed dose rates (nGy/hr)**	**Equivalent dose rate (mSv/yr)**
1	**A1**	570.08 ± 87.6	20.52 ± 5.2	18.95 ± 9.9	45.25 ± 12.5	0.3964 ± 0.1
2	**A2**	105.57 ± 24.9	18.94 ± 8.4	16.62 ± 6.7	23.53 ± 9.1	0.2061 ± 0.1
3	**A3**	404.95 ± 99.8	34.81 ± 13.6	19.33 ± 6.5	44.68 ± 14.3	0.3914 ± 0.1
4	**A4**	140.49 ± 35.8	23.87 ± 9.7	17.84 ± 6.5	27.92 ± 10.0	0.2446 ± 0.1
5	**A5**	254.55 ± 79.5	38.28 ± 11.4	29.54 ± 11.5	46.60 ± 15.8	0.4082 ± 0.1
6	**A6**	256.22 ± 68.6	26.54 ± 9.7	22.46 ± 8.7	36.97 ± 12.8	0.3239 ± 0.1
7	**A7**	527.91 ± 89.5	35.91 ± 11.4	19.41 ± 9.9	50.39 ± 15.2	0.4414 ± 0.1
8	**A8**	545.13 ± 87.5	26.41 ± 11.1	18.63 ± 7.8	46.52 ± 13.6	0.4075 ± 0.1
9	**A9**	323.64 ± 75.9	29.36 ± 9.3	13.43 ± 7.3	35.05 ± 12.0	0.3070 ± 0.1
10	**A10**	132.23 ± 18.7	19.44 ± 9.9	16.52 ± 6.5	24.80 ± 9.3	0.2173 ± 0.1
Mean Values		326 ± 66.7	27.41 ± 10.0	19.27 ± 8.1	38.17 ± 12.5	0.3344 ±0.1

Table 13. Radionuclide Concentration of Soil Samples (BqKg^{-1}) (Avwiri et al, 2011)

		Water (Bq/l)				
S/N	**Sample**	**K-40**	**U-238 (Ra-226)**	**Th-232 (Ra-228)**	Absorbed dose rates (nGy/hr)	Equivalent dose rates (mSv/yr)
1	**W1**	16.40 ± 7.3	8.24 ± 2.8	5.87 ± 2.0	7.80 ± 2.8	0.0683 ± 0.03
2	**W2**	26.74 ± 7.7	7.48 ± 3.3	7.44 ± 2.2	9.24 ± 3.2	0.0809 ± 0.03
3	**W3**	24.98 ± 9.8	9.32 ± 2.3	8.32 ± 2.5	10.54 ± 3.0	0.0923 ± 0.03
4	**W4**	19.84 ± 7.0	7.89 ± 3.0	7.89 ± 2.1	9.43 ± 3.0	0.0826 ± 0.03
5	**W5**	23.51 ± 9.7	8.04 ± 2.1	6.78 ± 2.3	8.91 ± 2.9	0.0781 ± 0.03
6	**W6**	32.08 ± 8.2	9.06 ± 3.2	8.29 ± 3.1	10.71 ± 3.8	0.0938 ± 0.03
7	**W7**	16.12 ± 7.2	9.41 ± 2.7	7.89 ± 2.5	9.92 ± 3.1	0.0869 ± 0.03
8	**W8**	27.16 ± 9.0	6.94 ± 3.5	5.20 ± 2.0	7.55 ± 3.2	0.0661 ± 0.03
9	**W9**	21.67 ± 7.4	5.99 ± 2.1	4.76 ± 2.1	6.62 ± 2.6	0.0580 ± 0.02
10	**W10**	39.15 ± 10.0	6.85 ± 1.8	7.34 ± 2.9	9.68 ± 3.1	0.0848 ±0.03
Mean Values		24.77± 8.3	7.92±2.7	6.96±2.4	9.03 ± 3.1	0.0791 ± 0.03

Table 14. Radionuclide Concentrations of Water Samples (Bql^{-1}) (Avwiri et al, 2011)

The determination of the equivalent radiation exposure (effective dose rate) for the immediate neighbourhood of the dumpsite indicate that the population in the vicinity of the site receives a dose that lies in the range of 0.2061 to 0.4414 $mSv.y^{-1}$ with a mean of 0.3344±0.1091 $mSv.y^{-1}$ from the soil and a dose that ranges from 0.0580 to 0.0938 $mSv.y^{-1}$ with a mean of 0.0791±0.0269 $mSv.y^{-1}$ from the water. The dumpsite therefore appears to pose minimal ionizing radiation risk to the environment and the population.

9. Ionizing radiation control strategies for Nigeria's hydrocarbon industry

The following strategies are proposed for the control and management of ionizing radiation in the region:

9.1 Identification of areas of radiation risks

Activities and locations with high ionizing radiation risks or potential for radiation hazards should be delineated. The reason for this is that radiation pollution and risks cannot be controlled if the location of the risk is unknown. Therefore, regular radiation monitoring in the region is to be sustained. Such radiation monitoring should include baseline surveys of oil and gas facilities and host communities, water and soil analyses, monitoring of well heads, production manifolds, storage tanks, flow stations, etc.

9.2 Establishment and enforcement of ionizing radiation limits for the hydrocarbon industry

Here such government agencies as the Nigeria Nuclear Regulatory Authority (NNRA) must enforce compliance with relevant laws by industry operators. Where existing laws are inadequate or obsolete they should be reviewed and appropriate legislations enacted.

9.3 Education and public enlightenment

Education of industry personnel and proper enlightenment of members of the public should form critical components of any ionizing radiation control strategy. Industry personnel, especially those most likely to be exposed to radiation, need to be trained to work safe and ensure that ionizing radiation is not spread.

Also, the general public, especially residents of communities that host oil and gas installations should be educated on the hazards of ionizing radiation.

9.4 Handling of ionizing radiation contaminated waste

Ionizing radiation contaminated waste generated by the hydrocarbon industry include sludge, scale, drilling pipes, storage tanks, etc. In the absence of appropriate control mechanisms, unintended spreading of ionizing radiation contamination with consequent contamination of areas of land and the environment and eventual exposure of the public can occur in the course of the handling, storage and transportation of ionizing radiation contaminated equipment or waste.

Used oilfield equipments should therefore be evaluated first to determine their radioactivity status before transportation; otherwise unintended spreading of ionizing radiation can occur when such materials as contaminated pipes and tanks are transported. Possible strategies for handling radioactive waste generated in the oil and gas industry include among others disposal in salt caverns, underground injection, and smelting (OGP, 2003).

Industry operators will have to study the Niger delta environment to determine the most appropriate strategies for the region.

9.5 Decommissioning of oil and gas production facilities

At some point in its productive cycle, an oil and gas facility such as a reservoir will become economically unviable for further exploitation and must therefore be properly disposed of rather than just abandoning it. This is the process of decommissioning. For example, available statistics (NNPC, 2004) show that there are 606 oil fields in the Niger Delta region, 251 of which are offshore, while the balance of 355 wells are on-shore. Also, of these, 193 wells are currently being exploited while 23 have been shut in or abandoned as no more viable and would therefore need to be properly decommissioned.
Among other reasons for decommissioning is the desire to limit the hazards of radioactive contamination. The steps in oilfield facility and equipment decommissioning include the following (IAEA, 2003):

i. Radiological assessment of equipments and facilities to ascertain radiation levels and therefore level of risk to personnel, the general populace and the environment.
ii. Submission of decommissioning plans, surveys and radiological reports on the equipments and facilities to relevant regulatory authorities such as the Nigeria Nuclear Regulatory Authority (NNRA) and such other agencies responsible for environmental health and safety especially as it relates to ionizing radiation.
iii. Decontamination of equipments and facilities to levels set by relevant regulatory bodies, especially if such equipments and facilities will become available for unrestricted public use.
iv. Radioactive waste management. This is the last step in the decommissioning procedure, where all hazardous radioactive wastes and the remaining contaminated items are disposed of in designated and approved radioactive waste disposal facilities.

10. Conclusion and suggestions for future research

It is obvious from this study that the Niger delta region of Nigeria is inundated with ionizing radiation as a result of the activities of the hydrocarbon industry and its subsidiary services. Though the profile in general does not indicate any immediate health complications both for the industry personnel and the general populace, the ionizing radiation patterns of the region is still crucial for the following reasons:
10.1. Low level radiations have long-term cumulative effects (Chang et al, 1997). Moreover for the hydrocarbon industry evidence exists on long term effect of low radiation dose. It has been observed that there is prevalence among hydrocarbon industry retirees and host community members of such diseases as eye cataracts, various kinds of cancer such as lung and bone cancer, leukaemia and mental disorder (UNDP, 2006; Otarigho, 2007). In the long term therefore, the current low radiation exposure could become a serious health hazard. It is therefore apparent that the present low radiation level in Nigeria's hydrocarbon belt should not be ignored.
10.2. Various research findings presented in this study show that in many specific locations, radiation levels exceed the expected normal background levels. The implication of this is that the ionizing radiation levels in the region are rising progressively so that the environment is gradually becoming unsafe for the general populace in the region.

10.3. Though the overall ionizing radiation profile for the region is that of low exposure rates, however evidence from the study indicates that in some of the locations the radiation levels exceed internationally recommended standards, especially for the general populace.
10.4. The activities of the industry are not abating. On the contrary, there appears to be more aggressive activities aimed at exploiting the abundant resources of the region with attendant increased introduction into the region of ionizing radiation. Increased oil and gas exploration, exploitation and production activities will result in increased radiation pollution due to increased radioactive waste generation and increased generation of such hydrocarbon industry sources of ionizing radiation as scales, sludge, formation water, etc.
10.5. The current practise of gas flaring poses the danger of radionuclide build-up in the atmosphere. As the work has shown, areas of high gas-related activities in the region have tended to experience marked ionizing radiation levels. Furthermore, when the flared gas comes in contact with rain water, it results in the radioactive pollution of the rain water. And like the water from the creeks and rivers, rain water in many parts of the Niger delta is an important source of water for various activities like bathing, washing, cooking and drinking.
10.6. It will be helpful to investigate the health challenges of the workers at the oil and gas facilities in the Niger delta to see if there is any correlation between ionizing radiation exposure and the health complaints of the workers.
10.7. Further research in the area should include:

i. Mathematical modelling of oil spill phenomenon in the area
ii. Mathematical modelling of impact of gas flaring in the area
iii. More extensive soil and water analyses of areas affected by oil spillage in the region so as to properly establish the impact of oil spillage especially considering that much of the population of the region are fishermen and rural subsistence farmers
iv. A study of the health challenges of oil and gas industry personnel and host community residents to determine any possible correlation between ionizing radiation and the prevailing health issues of these respective groups

11. References

Abali,B.K. (2009). Oil and Gas Exploration: What ONELGA suffers. Port Harcourt, B'Alive publications co.

Agbalagba, E. O , Avwiri, G. O and Chad-Umoren, Y. E. (2011). Radiological Impact of Oil and Gas Activities in Selected Oilfields in Production Land Area of Delta State, Nigeria (In press).

Agbalagba, O. E. and and Meindinyo, R. K. (2010). Radiological impact of oil spilled environment: A case study of the Eriemu well 13 and 19 oil spillage in Ughelli region of delta state, Nigeria. Indian Journal of Science and Technology, Vol. 3(9), 1001 – 1005

Agbalagba E.O., Meindinyo. R.K., Akpata, A.N. and Olali, S.A (2011). Assessment of Gamma-radiation Profile of Oil and Gas Facilities in Selected Flow Stations in the Niger- Delta Region of Nigeria. Indian Journal of Emerging Science and Technology (in press)

Arogunjo, M.A., I.P. Farai and I.A. Fuwape (2004). Impact of oil and gas industry to the natural radioactivity distribution in the delta region of Nigeria. Nigerian Journal of Physics, vol.16, 131-136.

Avbovbo, A. A. (1998). Tertiary Lithostratigraphy of Niger Delta: American Association of Petroleum Geologists Bulletin, vol. 62(2), 295-300

Avwiri, G. O. and Agbalagba, E.O. (2007). Survey of gross alpha and gross beta radionuclide activity in Okpare – Creek, Delta State, Nigeria. Asian Journal of Applied Science, vol. 7 (22), 3542 – 3542.

Avwiri, G.O., Chad – Umoren, Y.E., Enyinna, P.I. and Agbalagba, E.O. (2009). Occupational radiation Profile of oil and gas facilities during and off – production periods in Ughelli, Nigeria. Factia Universititatis, Series Working and Living Environmental Protection, Vol. 6(1).

Avwiri, G. O; Enyinna, P. I and Agbalagba, F. O.(2007). Terrestrial Radiation Around Oil and Gas Facilities in Ughelli, Nigeria. Journal of Applied Science, vol. 7, 1543 – 1546.

Avwiri, G. O., Owate, I. O. and Enyinna (2005). Radionuclide Concentration Survey of Soil, Sediments and Water in Aba River, Abia State, Nigeria. Scientia Africana, vol. 4(1&2), 67-72.

Avwiri, G.O. and Ebeniro, J.O. (1998). External Environmental Radiation in an industrial area of Rivers State, Nigeria. Nigerian Journal of Physics, vol. 10, 103 – 107.

Avwiri, G.O., Enyinna, P. I. and Agbalagba, E.O. (2008). Assessment of natural radioactivity concentration and distribution in river Forcados, Delta State, Nigeria. Scientia Africana Vol. 4(1 & 2), 128-135

Avwiri, G.O., Enyinna, P.I and Agbalagba, E.O. (2010). Occupational radiation levels in solid minerals producing areas of Abia State, Nigeria. Scientia Africana. Vol. 9 (1).

Avwiri, G.O., and Ebeniro, J.O. (2002). A survey of the background radiation levels of the sub-Industrial areas of Port Harcourt, Global Journal of Pure and Applied Sciences. Vol. 8(2), 111 – 113.

Avwiri, G.O. and Tchokossa, P. (2006). Radiological Impacts of Natural radioactivity along Aleto River due to a Petrochemical Industry in Port Harcourt, Rivers state, Nigeria. Journal of Nigeria Environmental Society (JNES), Vol. 3 (3), 315 – 323.

Avwiri, G.O., Mokobia, C.E. and Tchokossa, P. (2006). Natural radionuclide in borehole water in Port Harcourt, Rivers state, Nigeria. Radiation Protection Dosimetry, Vol. 123(4), 509 – 514, Oxford Journals UK

Avwiri, G.O., Nte, F.U. and Olanrewaju, A.I. (2011). Determination of radionuclide concentration Of land fill at Eliozu, Port Harcourt, Rivers State. Scientia Africana (in press).

Baweja A. S, Joshi S.R. and Demayo A . (1987). Report on the National Radionuclide monitoring program, (1981-1984) Environment Canada, Ottawa, Scientific services No.156.

Beka, F. T., and Oti, M. N., (1995). The distal offshore Niger Delta: frontier prospects of a mature petroleum province, *in*, Oti, M.N., and Postma, G., eds., Geology of Deltas: Rotterdam, A.A. Balkema, p. 237-241.

Briggs-Kamara, M.A; Sigalo, F.B; Chad-Umoren, Y.E. and Kamgba, F.A. (2009). Terrestrial Radiation Profile of a Nigerian University Campus: Impact of Computer and Photocopier Operations. Journal Facta Universitatis: Working and Living Environmental Protection, vol 6 (1), 1 – 9

CERN (1995). Safety Guide for Experiments at European Council for Nuclear Research, CRN, Part III – Advice, 40, Ionizing Radiation. (http://cern.web.cern.../40).

Chad-Umoren, Y. E and Briggs-Kamara, M. A (2010). Environmental Ionizing Radiation Distribution in Rivers State, Nigeria. Journal of Environmental Engineering and Landscape Management, vol. 18(2), 154–161

Chad-Umoren, Y. E and Obinoma, O (2007). Determination of Ionizing Radiation Level of the Main Campus of the College of Education, Rumuolumeni, Rivers State, Nigeria. Int'l Journal of Environmental Issues, vol. 5 (1 and 2), pp 5 -10

Chad-Umoren, Y. E; Adekanmbi, M and Harry, S. O. (2006). Evaluation of Indoor Background Ionizing Radiation Profile of a Physics Laboratory. Journal Facta Universitatis: Working and Living Environmental Protection., Vol 3 (1), pp 1 – 8

Chang, W.P; Hwang, BF; Wang, D. and Wang, JD (1997). Cytogenetic Effect of Chronic Low-Dose, Low-Dose-Rate Gamma Radiation in Residents of Irradiated Buildings. Lancet. 350:330 – 333.

Ebong I.D.U. and Alagoa, K. D. (1992a). Estimates of gamma – ray background air exposure at a fertilizer plant. Discovery innovate, 4, 25-28.

Ebong, I.D.U. and Alagoa, K. D. (1992b) Fertilizer Impact in ionization radiation background at a production plant. Nig. J. Phys., vol. 4, 143 – 149.

Evamy, B.D., Haremboure, J., Kamerling, P., Knaap, W.A., Molloy, F.A., and Rowlands, P.H., (1978). Hydrocarbon habitat of Tertiary Niger Delta: American Association of Petroleum Geologists Bulletin, vol. 62, p. 277-298.

Foland, C.K., T.K. Kirland and K. VinniKoov (1995). Observed climate variations and changes (IPCC scientific Assessment) Cambridge University Press New York, Pp. 101 – 105.

IAEA (2003). Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry. International Atomic Energy Agency Vienna, 2003 Safety Reports Series No.34

ICRP (1990). Recommendations of International Commission on Radiological Protection., Annals of ICRP-60, Pergamon press, Oxford.

ICRP (1977). Recommendation of the International Commission on Radiological Protection. ICRP Publication 261 (3).

Jibiri, N.A.O., Mbawonku, A.O., Oridale A.A. and Ujiagbadion C. (1999). Natural Radionuclide concentration levels in soil and water around cement factory, Ewekoro, Ogun State. Nigeria Journal of Physics, Vol. II, 12 – 16.

Laogun, A.A., N.O Ajayi and S.A. Agaja (2006). Variation in well head gamma radiation levels at the Nigeria Petroleum development company oil field, Ologbo Ede State, Nigeria. Nig. J. Phys, 18(1), 135-140.

Louis, E. A; Etuk, E. S. and Essien, U (2005). Environmental Radioactive Levels in Ikot Ekpene, Nigeria. Nig. J. Space Res. Vol 1, 80 – 87.

ECN(2003).National Energy Policy. The Presidency: Energy commission of Nigeria. Federal Capital Territory, Abuja, Nigeria, pp: 82

NNPC Yearly Bulletin (2004)**:** History of the Nigerian Petroleum Industry, Nigeria pp 54 – 64

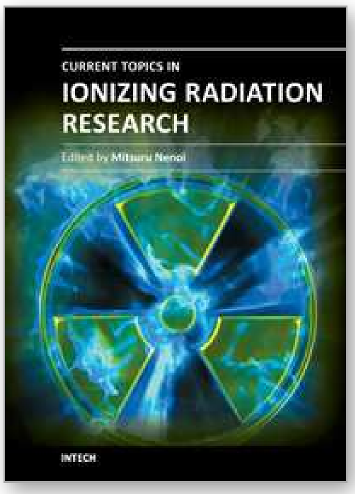
OGP (2008) Guidelines for the management of Naturally Occurring Radioactive Material (NORM) in the oil & gas industry, International Association of Oil & Gas Producers

Ononugbo, C. P; Avwiri, G. O. and Chad-Umoren, Y. E. (2011): Impact of Gas Exploitation on the Environmental Radioactivity of Ogba/Egbema/Ndoni Area, Nigeria. Energy and Environment (In press).

Otarigho, M.D., (2007). Impact of oil spillage on the people of Ughelli South Local Government Area, Delta State. J. Environ. Res. & Policies, vol. 2, 44 – 50.

United Nations Development Programme (UNDP) (2006). Niger Delta Human Development report: Environmental and Social Challenges in the Niger Delta. UN House, Abuja, Nigeria.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993). United Nations sources and effects of atomic radiation 1993, Report to the general Assembly with scientific Annexes, United Nations, New York 1993.992.



Current Topics in Ionizing Radiation Research

Edited by Dr. Mitsuru Nenoi

ISBN 978-953-51-0196-3
Hard cover, 840 pages
Publisher InTech
Published online 12, February, 2012
Published in print edition February, 2012

Since the discovery of X rays by Roentgen in 1895, the ionizing radiation has been extensively utilized in a variety of medical and industrial applications. However people have shortly recognized its harmful aspects through inadvertent uses. Subsequently people experienced nuclear power plant accidents in Chernobyl and Fukushima, which taught us that the risk of ionizing radiation is closely and seriously involved in the modern society. In this circumstance, it becomes increasingly important that more scientists, engineers and students get familiar with ionizing radiation research regardless of the research field they are working. Based on this idea, the book "Current Topics in Ionizing Radiation Research" was designed to overview the recent achievements in ionizing radiation research including biological effects, medical uses and principles of radiation measurement.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821